Final Report to Virginia Coastal Zone Management Program

Enhancements to Blue Infrastructure Tools ("Coastal GAP")

NOAA Task 92.06
FY 2005

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December 19, 2007
(resubmitted February 15, 2008)

This project was funded by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through grant number NA05NOS4191180 of the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management under the Coastal Zone Management Act of 1972, as amended.

Background

INSTAR (**IN**teractive **ST**ream **A**ssessment **R**esource; http://instar.vcu.edu) is a dynamic and interactive internet application built on ESRI's ArcIMS platform and supported by dedicated servers at Virginia Commonwealth University's Center for Environmental Studies. INSTAR allows users to access and manipulate a comprehensive (and growing) database representing over 2,000 stream and river collections statewide. Accessible data represent fish and macroinvertebrate assemblages, instream habitat, and stream geomorphology. The application supports user-driven database queries, mapping functions, and quantitative biological assessments of stream reaches and watersheds, using algorithms and ecological models that compare user-selected sites to appropriate regional reference conditions. INSTAR is accessible from most computers via the internet and navigation throughout the application is relatively easy.

The INSTAR program began in 2003 as a collaboration between the Center for Environmental Studies at VCU and several agencies, including the Virginia Department of Conservation and Recreation and the Virginia Coastal Zone Management Program. The program goal is to develop and promote statistically sound analytical and decision-support tools for blue infrastructure (stream ecological health) assessments statewide, but with particular emphasis on the Virginia Coastal Zone. Specifically, INSTAR supports detailed geospatial analyses of aquatic living resources, in-stream and riparian habitat, and measures of the ecological integrity of streams and watersheds (i.e., *Virtual Stream Assessment, VSA; Modified Index of Biotic Integrity, mIBI*). INSTAR**,** and the extensive aquatic resources database on which it runs, were developed to support a variety of stream assessment, management, and planning activities aimed at restoring and protecting water quality and aquatic living resources throughout the Commonwealth. Currently, over 2,000 stream locations across Virginia are represented within the INSTAR database and most of these sites are accessible through the INSTAR online interface.

The database that VCU has developed (i.e., expanded) under this grant complements and enhances the limited available information on stream ecological health in many parts of the state, including the Coastal Zone (CPMT; USEPA 1997, Maxted et al. 2000), for low-gradient streams and rivers of the Coastal Plain physiographic province, and other indices based on the EPA's Rapid Bioassessment Protocols for streams and rivers (Barbour et al. 1999). In addition, the fish community data are expected to be particularly useful for the assessment of larger, non-wadeable streams and rivers in the Coastal Zone, which are not amenable to macroinvertebrate sampling. Because of the complementary nature of the purpose and research design, much of the project management, assessment and oversight follows the protocols of VADEQ Biological Monitoring of Virginia Quality Assurance Project Plan for Wadeable Streams and Rivers (2006). The current project through Virginia Coastal Zone Management Program expanded significantly the geographic scope and data density of the existing INSTAR database, supporting higher-resolution (finer-scale) and more accurate assessments of stream ecosystem health within the Coastal Zone. These new data will enhance decision support tools (e.g. Coastal GEMS) and related geospatial analyses (Figure 1) that are used extensively by VCZMP partners and regional stakeholders.

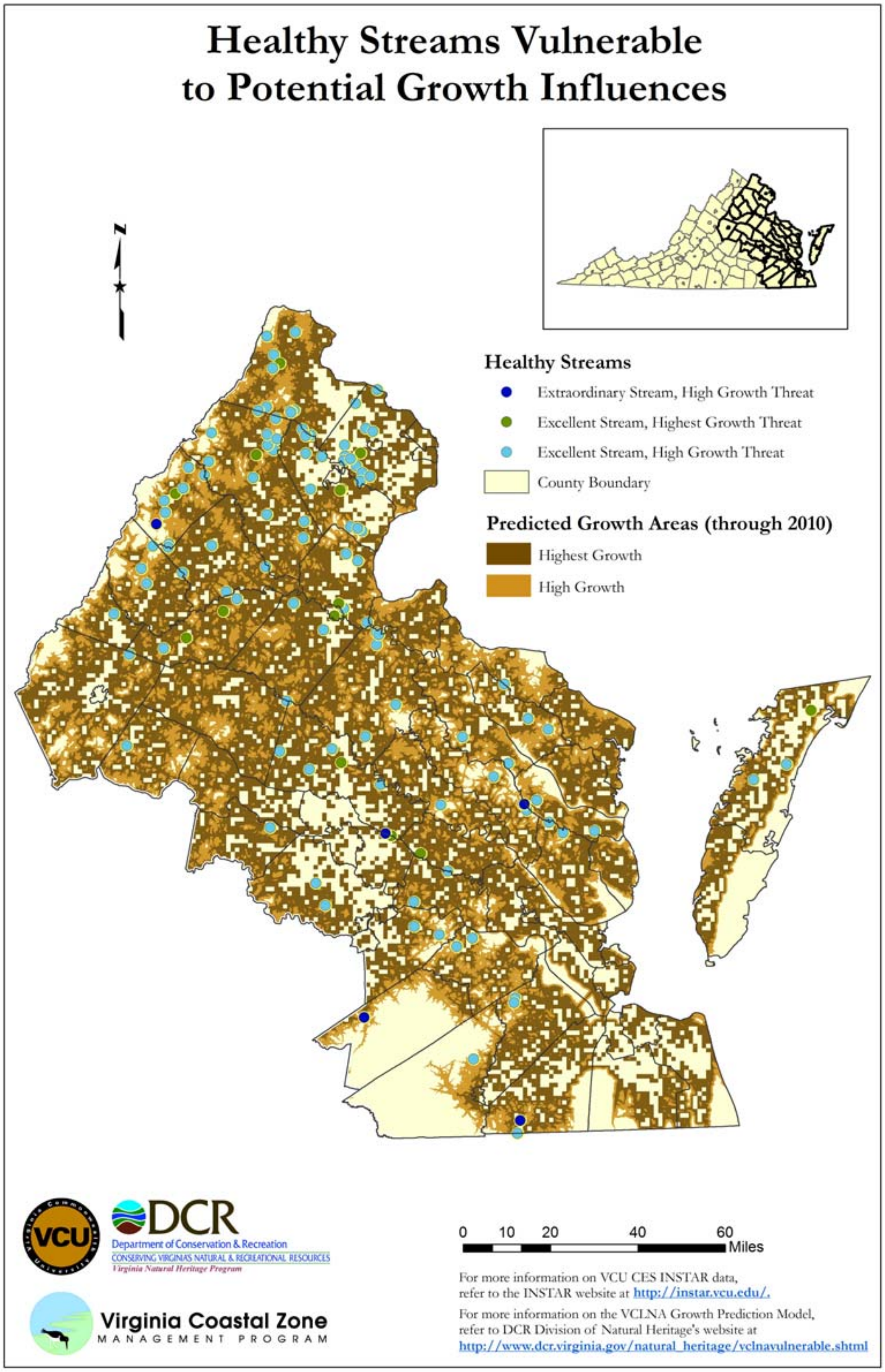

Figure 1. INSTAR-based analysis of healthy streams that vulnerable to projected development threats in the Virginia Coastal Zone.

Currently, the INSTAR program includes most of the Chesapeake Bay basin within Virginia and outputs are fully compatible with stream assessment tools and databases (Maryland Biological Stream Survey, MBSS) representing the Maryland portion of the Bay watershed. A new, and user-friendly, version of INSTAR is being completed with funding from Virginia DCR will be available early in 2008 and will benefit from the expanded dataset generated by this grant. The goal of this project was to expand INSTAR coverage in the Virginia Coastal Zone to eliminate data gaps and to support reach-level ecological analysis in all targeted hydrologic units (HUCs, n=250). Previous data development efforts by VCU did not create sufficient data densities in all targeted coastal HUCs to support reach-level analysis.

Project Approach

Probabilistic study reaches for *INSTAR* sampling are selected through a statistically powerful stratified (by stream order) random design. Within each geo-referenced reach (150-500 m), fishes are sampled quantitatively using electrofishing equipment (backpacks, tote barge units, boats) and standard methods. Backpack and tote barge sampling is performed throughout the entire reach in a single pass. Boat electrofishing may include additional sampling effort depending on stream width and habitat variability. All fishes are identified to species in the field, checked for anomalies, and released. Macroinvertebrates are collected using modified EPA Rapid Bioassessment Protocols (RBP III) for single habitat collections using D-frame dipnets. Each major stream habitat type is sampled separately and collections are returned to the VCU lab for identification to the lowest practical taxon and enumeration. Data are compiled into SQL databases and application macros within INSTAR calculate over 50 separate metrics and ecological variables, including those typically generated with the Index of Biotic Integrity (IBI) and Rapid Bioassessment Protocol (RBP). INSTAR assesses the ecological health of streams within watersheds based on percent comparability to the appropriate (e.g. basin, stream order) regional reference condition (i.e., virtual stream). Sampling for this grant was conducted during the period 1 September, 2006 and 15 December, 2007 and at water temperatures above 5°C and water conductivities above 30 μmhos. A more detailed description of the project methods is given below and at http://instar.vcu.edu.

Stream Ichthyofauna Sampling

Virginia Commonwealth University, Center for Environmental Studies (CES), uses various quantitative sampling gears and procedures for freshwater fish assemblages depending on the size and geomorphology of the stream, water quality characteristics, and flow conditions. The large majority of wadeable streams (typically 1^{st} through 3^{rd} order) are sampled using a single backpack electrofishing unit (Smith-Root LR-20). Larger streams may warrant the concurrent use of two backpack units and crews in order to effectively sample a wider or more complex channel. Larger streams and rivers (4^{th} or 5^{th} order) that are wadeable but have sufficient width and depth to decrease substantially the efficiency of backpack units are sampled with a tote boat unit (Smith-Root SR-6). Non-wadeable streams and rivers (5^{th} order or greater) are sampled using electrofishing boats (Smith-Root SR-16H) units. Selection of appropriate gears and protocols is based on the best professional judgment of an experienced regional fish biologist. Electrofisher settings (e.g. output voltage, waveform, etc.) for each sampling event optimized sampling efficiency and minimized fish mortality, based on ambient conditions and operator experience. Sites that could be sampled effectively by wading were sampled by backpack electrofisher; comparatively high-order streams and rivers were sampled by electrofishing boat. Transitional sites (e.g. deep pools and wide, but wadeable, channel) were sampled by tote barge.

Stream Macroinvertebrate Sampling

Macroinvertebrates are collected using modified EPA Rapid Bioassessment Protocols (RBP III) for multiple habitat collections (Barbour et al. 1997). D-frame dip nets are used to sample macroinvertebrates from major habitat types found within each 150-meter study site. Examples of habitat types include undercut banks, hard substrate (gravel, etc.) riffles, leaf litter, and woody debris. Each habitat type is sampled separately and then composited into one sample. Dip nets are swept, jabbed, and/or kicked in and through habitats in order to secure a representative sample of the macroinvertebrate assemblage. Samples are processed in the laboratory where the first 200 organisms encountered are identified to the lowest practical taxonomic level (typically genus) and enumerated.

Site Selection

Probabilistic sampling locations (stream reaches) were determined by VCU using standard GIS methods. The length of the sampling reach for each event was based on both time and distance criteria. Specifically, in small (i.e., channel width <= 4 m), wadeable streams (backpack or tote barge unit), sampling represented 500 seconds of shock time *or* 150 m of stream channel. Collections in larger rivers and streams (i.e., > 4 m channel width) based on boat electrofishing or tote barge represented 1,600 seconds of shock time *or* a reach length corresponding to 40 times the mean channel width (cumulative, if multiple passes). Sampling always proceeded upstream from the downstream end of the reach.

Selection of probabilistic study sites is based on a stratified (by stream order), probabilistic design to be representative of stream conditions within the watershed. The number of sites sampled is based on the results of a statistical power analysis, the amount of available resources, and the quantity and quality of archival data for the basin. ArcGIS software is used to generate points (study site locations) in 14 digit watersheds, using a probabilistic site selection program.

Stream Habitat Assessment

An evaluation of habitat quality is critical to any assessment of ecological integrity and was performed at each site at the time of the biological sampling. In general, instream habitat and biological diversity in streams and rivers are closely linked. This project employed EPA's standard Rapid Habitat Assessment protocols for low-gradient streams. Qualitative habitat assessment is conducted at each bioassessment site by trained and experienced individuals. Both in-stream and riparian habitat are important determinants of the composition, structure, and function of biotic communities. Habitat quality also often is an indicator of water quality stressors in streams. In addition, poor habitat quality can obscure the effects of specific pollutants. A systematic assessment of in-stream and riparian habitat quality thus is necessary to fully assess water quality conditions in streams and rivers. Habitat assessment is considered an important tool for the final evaluation of impairment or stream health. Both the quality and quantity of available habitat can affect the resident biological community structure and composition. The final conclusion of a bioassessment should take into consideration the habitat quality of a water body and whether the health of aquatic biological communities is limited by habitat conditions. Procedures for habitat assessments followed that of the EPA Rapid Bioassessment Protocols (Barbour et al. 1999). No water quality parameters were measured.

Data Analysis

Compiled empirical data (i.e., variables and metrics) were analyzed with multivariate techniques (e.g. correspondence analysis (CA), detrended correspondence analysis (DCA), canonical correspondence analysis (CCA), principal components analysis (PCA), and multiple regression). The site scores (i.e., coefficients from the final response model) are entered as the response variable and significant ($P<0.05$) biotic and abiotic variables and metrics are entered as explanatory variables. Finally, a series of reference stream models (i.e., *virtual* reference streams) are created for each ecoregion and stream order. We used Gower's similarity index to compare empirical scores obtained from sampled stream sites and reaches to the appropriate regional reference stream, generating an index of stream health (i.e., **Virtual Stream Assessment, VSA**, score; range 0-100%) as a measure of percent comparability to the appropriate (*virtual*) reference condition model (Figure 2). Current reference stream models for coastal streams include variables representing fish and macroinvertebrate assemblage structure, instream habitat, and geomorphology, and have substantial explanatory power (R^2 up to 0.74). This integrative approach eliminates many of the limitations typically associated with traditional bioassessment methods (e.g. RBP, IBI), including lack of appropriate reference sites and stream classifications that are based on a single ecological component (e.g. biotic *versus* abiotic, fishes *versus* macroinvertebrates) that may not be diagnostic under many conditions.

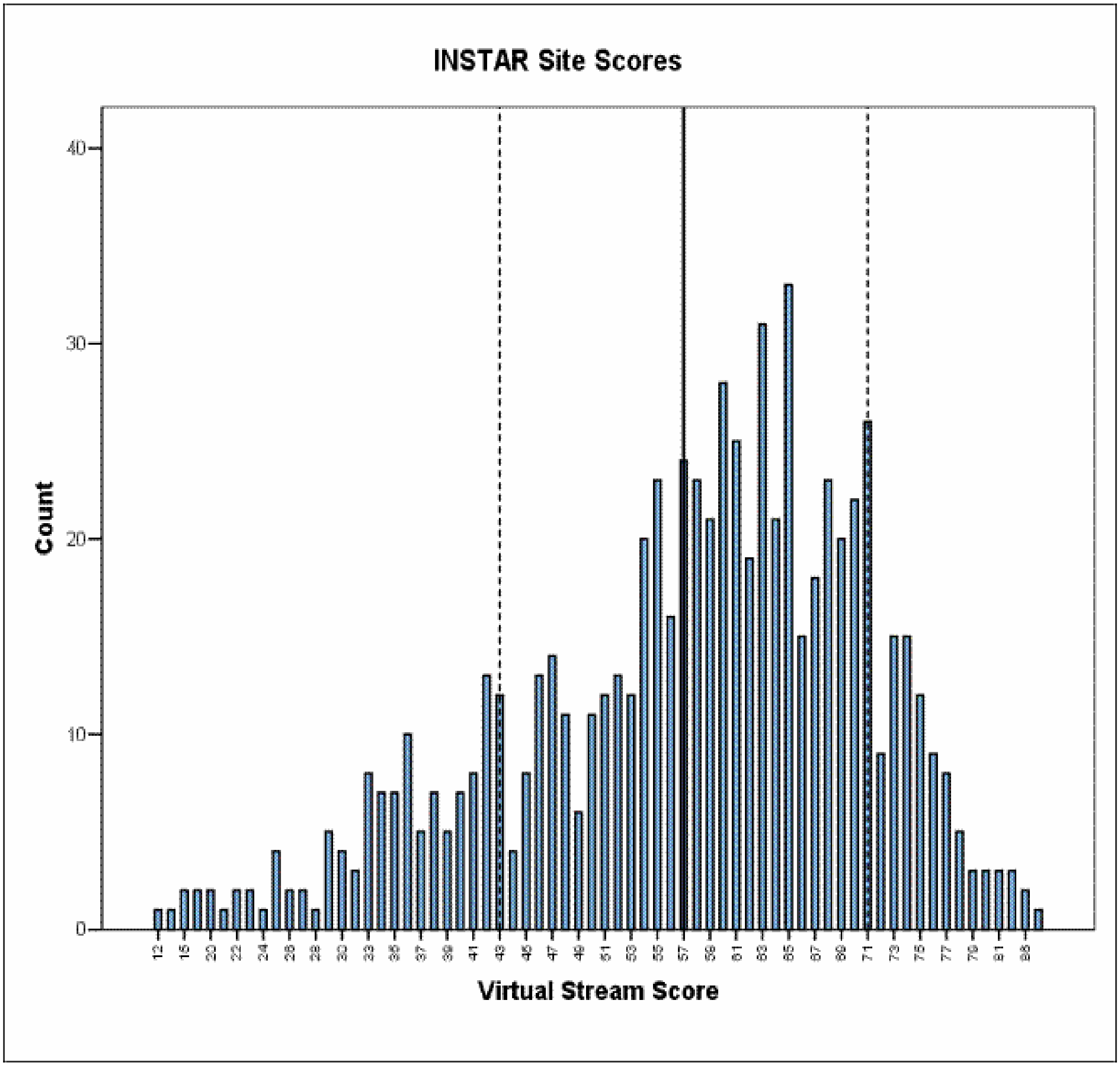

Figure 2. Empirical distribution of VSA (i.e., virtual stream assessment) scores for Virginia coastal streams, as the percent comparison of each collection to the appropriate regional reference condition. The solid line represents the median VSA score and the dotted lines are +/- one standard deviation.

Specific Grant Accomplishments

During the grant period, VCU biologists, including David Hopler, Steve McIninch, Drew Garey, Greg Garman, Matt Balazik, and Casey Seelig, conducted quantitative sampling of stream fish and macroinvertebrate assemblages, and instream habitat, within targeted HUCs with less than a minimum of three INSTAR collections. Targeted HUCs were within the jurisdictional Coastal Zone and had sufficient freshwater stream habitat (tidal or nontidal) to warrant classification and were > 5,000 acres in area. Field sampling employed standard protocols and a probabilistic design. Data will be subjected to approved QA procedures and entered into the INSTAR database for reference model development and site classification. A total of 176 stream collections were completed within the Coastal Zone during this period. All fish and macroinvertebrate community data and stream habitat data were entered into the INSTAR SQL database and QA'd. During the same period, VCU finished migration of the geospatial component of INSTAR to the new 6th-order HUCs, which are considerably smaller (i.e., higher resolution) than the previous watershed boundaries. This change has the potential to increase the spatial resolution of INSTAR-based stream assessments by a factor of three, and meet the 'reach-level' of analysis. New data provided by this effort were used to refine virtual reference models for the Coastal Zone and identify a subset of approximately 120 'Healthy Streams' in the Coastal Zone, based on statistically valid criteria (e.g. mean and standard deviation of VSA scores; Figure 2). The number of Healthy Streams should increase, as new stream collections and data are being added to INSTAR on a regular basis. The proportion, however, should remain relatively constant around 12-14% of total streams in the Coastal Zone.

New data generated by these activities were also used to refine metrics and scoring criteria for the modified Index of Biotic Integrity (mIBI), which is used by INSTAR to classify watershed health. Finally, VCU has collaborated with Dr. Dan Dauer, Old Dominion University, regarding the integration of his Benthic IBI data into the Coastal GEMS Internet mapping application (www.deq.virginia.gov/coastal/coastalgems.html) as a geospatial data layer.

Project A: Closing Data Gaps in the INSTAR Stream and Watershed Assessment Network for the Virginia Coastal Zone

The Virginia Coastal Zone Management Program has supported the development and application of a comprehensive and integrative assessment tool for coastal streams and rivers, and for the critical ecological services that these systems provide. The INSTAR application combines an extensive and dynamic database on aquatic living resources and stream habitat with state-of-the-art information technologies. A previous phase of database development for INSTAR more than doubled the number of assessed stream locations (FY2004 Tasks 84 and 93.04), primarily within the coastal region, to an average of nearly 10 quantitative collections of fishes and/or macroinvertebrates for each 5th-order HUC. During the same period, however, VCU and VCZMP personnel agreed to migrate the geospatial component of INSTAR to the new 6th-order HUCs, which are considerably smaller than the previous watershed boundaries. However, as a consequence of INSTAR's probabilistic sampling design and the migration to smaller geospatial (i.e., hydrologic) units, significant data gaps will exist in the coverage of the Coastal Zone by the INSTAR application. The work completed by this grant restored appropriate data density for statistically valid stream health and living resources (blue infrastructure) classification and assessment based on the new, 6th order HUCs, within the Virginia Coastal Zone.

<u>Completed Objectives</u>

1. Conducted additional, quantitative sampling of stream fish and macroinvertebrate assemblages within targeted Coastal Zone HUCs with less than a minimum of three INSTAR collections. Targeted HUCs fell ***completely*** within the jurisdictional Coastal Zone and had sufficient freshwater stream habitat (tidal or nontidal) to warrant INSTAR classification. Additional criteria (e.g. > 5,000 acres in area) were also applied in some cases to develop a final list of targeted HUCs, which were sampled by standard protocols and based on a probabilistic design. Data were subjected to approved QA procedures and entered into the INSTAR database for reference model development and site classification.

2. Conducted additional, quantitative sampling of stream fish and macroinvertebrate assemblages within targeted HUCs with less than a minimum of three INSTAR collections. Targeted HUCs will fell ***partially*** within the jurisdictional Coastal Zone and had sufficient freshwater stream habitat (tidal or nontidal) to warrant classification. Additional criteria (e.g. > 5,000 acres in area) were also applied to develop a final list of targeted HUCs, which were sampled by standard protocols and based on a probabilistic design. Data were subjected to approved QA procedures and entered into the INSTAR database for reference model development and site classification.

Project B: Integration of a Benthic Index of Biotic Integrity (bIBI) Dataset into the Coastal GEMS Application

The Virginia Coastal Zone Management Program (VCZMP) has supported the development of two comprehensive, geospatial databases related to coastal landscapes in the Commonwealth. The first of these—the Virginia Conservation Lands Needs Assessment (VCLNA)—classifies high-quality green (i.e., terrestrial) ecological infrastructure, and was created by the Virginia Natural Heritage Program at the Dept. of Conservation and Recreation. The second database—INSTAR—will be one of the primary inputs related to blue infrastructure for the Coastal GEMS Internet mapping application, which is currently under development by the Virginia CZM Program and VCU. Unfortunately, blue infrastructure assessments using INSTAR are limited primarily to freshwater (tidal and nontidal) aquatic systems, resulting in a limited amount of information for Coastal GEMS representing estuarine and Chesapeake Bay mainstem habitats in Virginia. This data limitation is unfortunate because many of the major coastal environmental policies (e.g. Tributary Strategies) and regulations (e.g. Chesapeake Bay Preservation Act) in Virginia are based on the assumption of important (i.e., causal) ecological linkages between the coastal landscape (i.e., land-use and tributary health) and the condition and status of Chesapeake Bay.

An extensive dataset for the Chesapeake Bay and major tributaries, developed by the long-term, benthic monitoring program at Old Dominion University (Benthic Index of Biotic Integrity; Dr. Daniel Dauer; sub-contractor), may be compatible with INSTAR-based assessments of freshwater streams and rivers. Hence, integration of the existing Benthic IBI (estuarine) dataset into Coastal GEMS could represent a significant contribution to blue infrastructure assessment in Virginia and would leverage a substantial prior investment of resources by federal and state agencies.

bIBI Project Methodology

Benthic Index of Biotic Integrity (bIBI) data were obtained from Dr. Dan Dauer, Old Dominion University, in Microsoft Excel format. Data were imported as a database file (dbf) and imported into Environmental Systems Research Institute's (ESRI) ArcMap® software. The latitude and longitude of the sampling stations were located inside the table and were used to generate point locations for each record. A total of 3,395 collections/records appeared in the table from 1996 to 2006 (Figure 3). The bIBI dataset was then clipped to the state boundary to eliminate any records that were located outside of the Commonwealth of Virginia. This operation reduced the number of stations from 3,395 to 2,075. The following table shows the river drainage and number of bIBI collections. The bIBI data and basic information about this dataset are found in a fact-sheet which appears in Coastal GEMS.

Drainage	Stations
Chesapeake bay	247
Elizabeth River	392
James River	473
Potomac	331
Rappahannock	301
York	331

Completed Objective

1. Converted data representing approximately 3,400 benthic IBI collections (Dr. Dan Dauer, Old Dominion University) in Virginia tributaries and the Chesapeake Bay, into a comprehensive, geospatial (GIS) coverage for Coastal GEMS. The resulting data layer classifies the ecological integrity (i.e., 'health') of estuarine waters based on an analysis of the benthic macroinvertebrate assemblage by standardized (bay-wide) metrics and scoring criteria developed by Dr. Dauer (Figure 4). These metrics are not dissimilar in concept from the metrics used by INSTAR to classify stream and river segments (Figure 5). Data were used to create a geospatial layer in the Coastal GEMS application (version 2.0) as the deliverable for Project B.

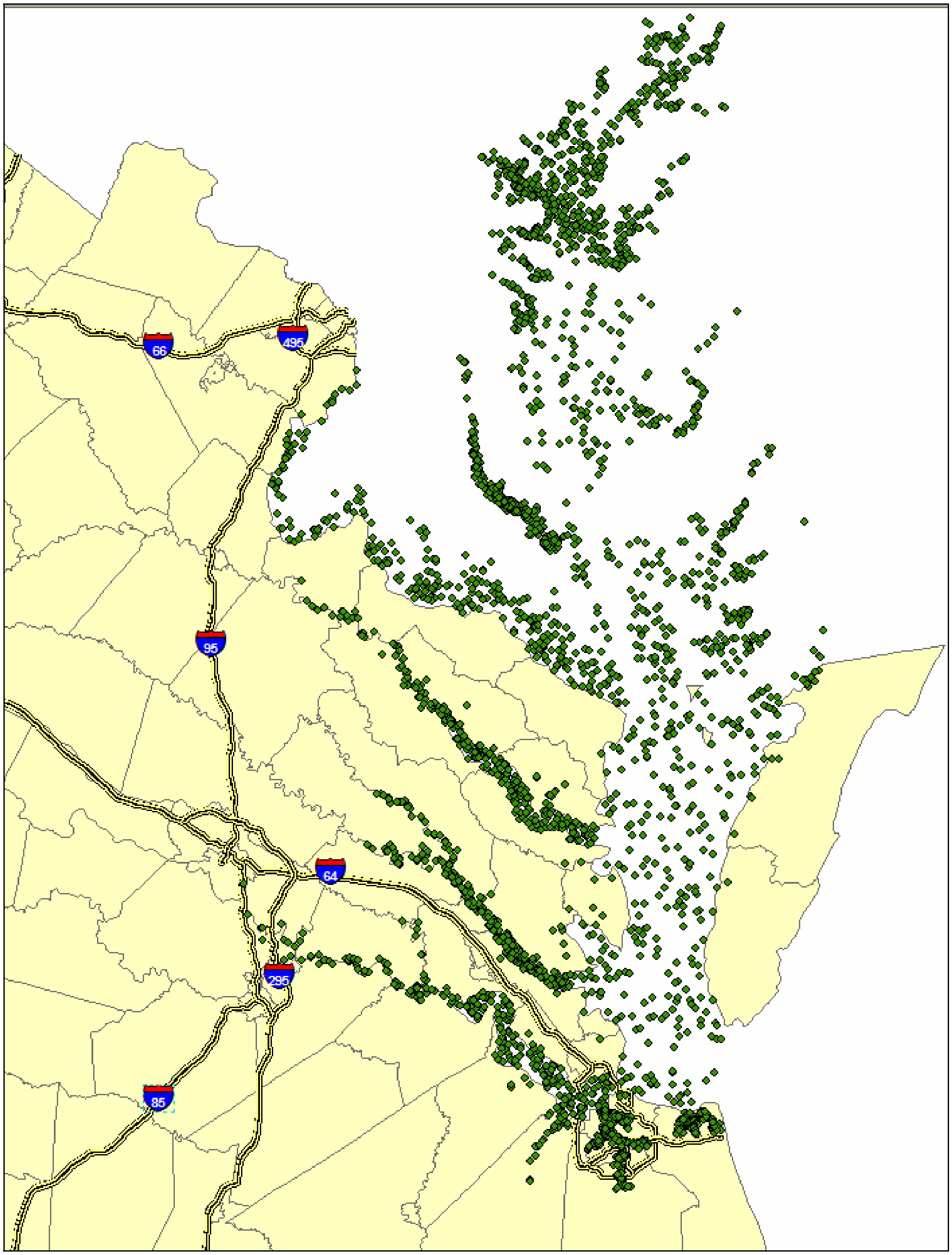

Figure 3: Approximately 3,400 bIBI collections, 1996 to 2006, in Chesapeake Bay and major tributaries (raw data provided by D. Dauer, ODU).

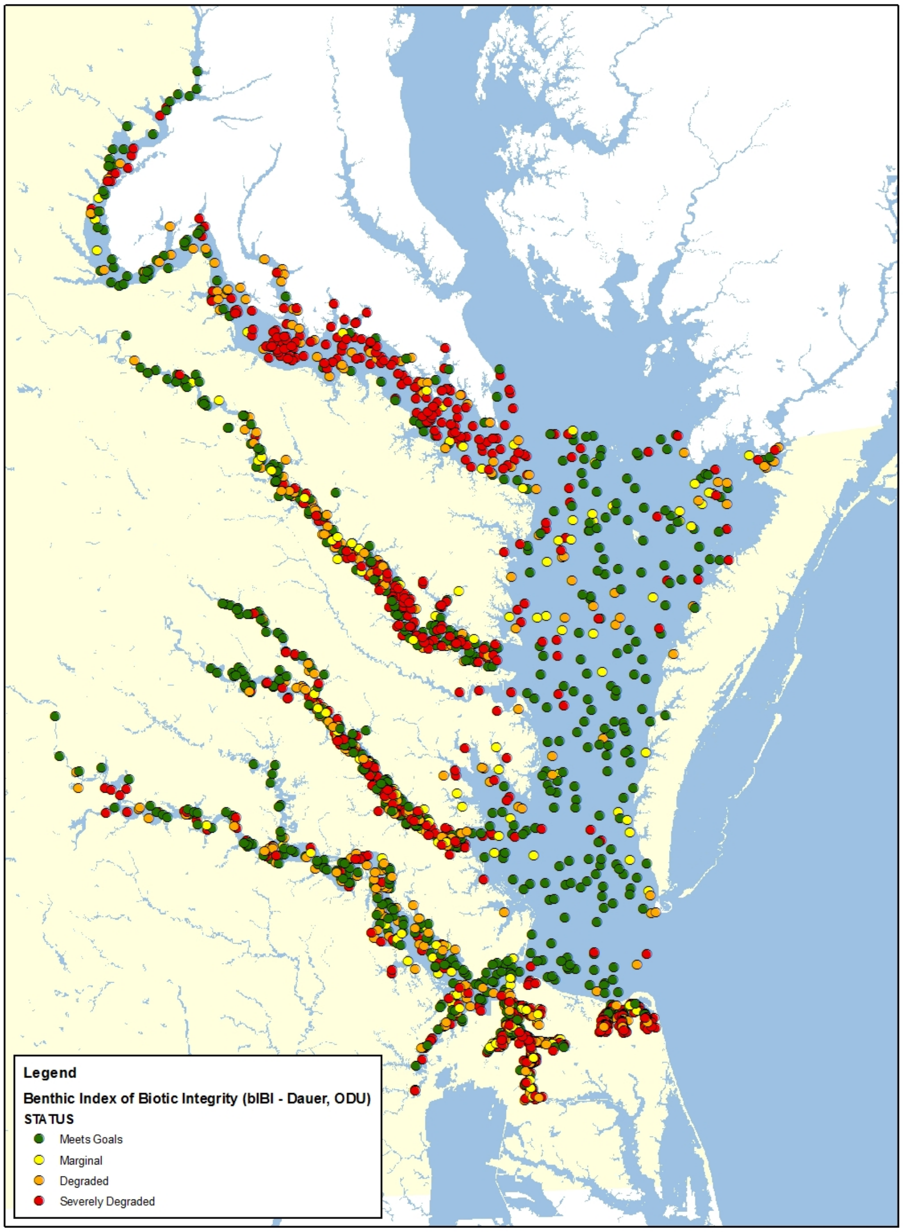

Figure 4. Benthic Index of Biotic Integrity (bIBI) sample locations within Virginia coastal waters, classified by integrity status, for inclusion into the Coastal GEMS data portal (raw data provided by D. Dauer, ODU).

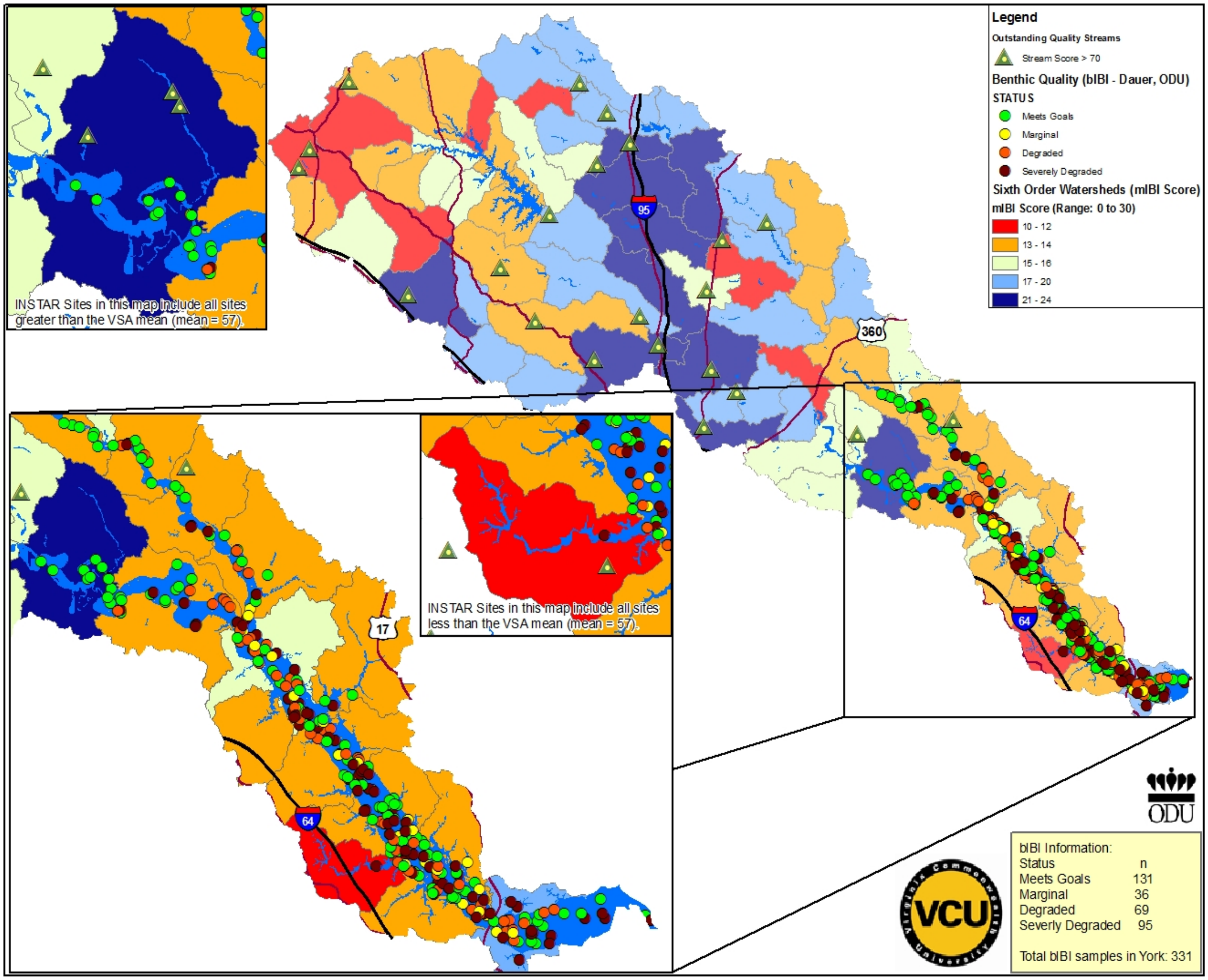

Figure 5: Selected bIBI locations (York River basin) and INSTAR-based classification of stream health by sixth-order watershed. Insets demonstrate possible correlation among large-river bIBI scores and stream integrity (INSTAR's mIBI metric) of adjacent watersheds. This putative connection between landscape and large tributary may warrant further investigation.